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Original Article

On-farm management practices against rice root weevil (*Echinocnemus oryzae* Marshall)

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ABSTRACT

Rice is the staple food of over half the world's population and occupies almost one-fifth of the global cropland under cereals. The rice root weevil, *Echinocnemus oryzae* Marshall, (Coleoptera: Curculionidae) has posed a problem in paddy cultivation areas in India. The damage by this root weevil results in a significant decrease in root and shoot biomass and ultimately the yield of rice plants. Studies were conducted to test the effective management practices of rice root weevil using a seedling treatment with chlorpyriphos alone and in combination with a soil application of chlorpyriphos, fipronil and cartap hydrochloride during 2013 and 2014. The benefit:cost (B:C) ratio was also determined from the marketable yield and cost of treatments incurred in the technology to justify the economic viability of the appropriate technology management against *E. oryzae*. Reductions in tillers/hill (35.2% and 26.27%) and, in panicles/hill (44.0% and 31.96%) were observed during 2013 and 2014, respectively. The least number of root weevils (3.67 and 3.13) were observed in comparison to no root weevil management practice (23.53 and 32.53) during 2013 and 2014, respectively, from the treatment of seedlings prior to transplanting with chlorpyriphos at 3 mL/L of water followed by soil application with cartap hydrochloride at 20 kg/ha. The highest numbers of tillers/hill (25.00 and 23.60), numbers of panicles/hill (20.00 and 19.40), yield (5.41 t/ha and 4.57 t/ha) and B:C ratio (1.75 and 1.48) were also observed from the same treatment during 2013 and 2014, respectively.

Introduction

Rice, *Oryza sativa*, is the most important staple food for more than two billion people in Asia and hundreds of millions of people in other parts of the world (Ladha and Peoples, 1995). India is the second largest producer and consumer of rice in the world, with rice production in India exceeding 100 million t in 2011–2012 and accounting for 22.81% of global production in that year; furthermore, the productivity of rice has increased from 1984 kg/ha in 2004–2005 to 2372 kg/ha in 2011–2012 (Anonymous, 2012).

There are two major factors which are responsible for low yields in paddy—adverse weather (floods, drought, typhoons, etc.) and pest epidemics (Li and Wassmann, 2011; Allara et al., 2012). Therefore, there is wide scope for increasing production of rice per unit area to mitigate these two factors. There are a number of biotic factors which limit the production but the magnitude of infestation of rice root weevil from the nursery stage to the early stage of transplanting plays a crucial role in quantum production (Singh and Dhaliwal, 1990).

The rice water weevil, *Lissorhoptrus oryzophilus* Kuschel, is one of the most destructive insect-pests of paddy in the USA (Way, 1990; Tindall et al., 2004; Zou et al., 2004) and also has gained pest status in the rice-producing regions of Eastern Asia (Lee and Uhm, 1993; Zhai et al., 1997; Saito et al., 2005). Likewise, the rice root weevil, *Echinocnemus oryzae* Marshall, (Coleoptera: Curculionidae) has posed a problem in paddy cultivating areas in India (Tirumala Rao, 1952). Now in India, the eastern part of Uttar Pradesh has recently gained wider importance with regard to the rice root weevil due to its introduction into other rice-producing regions (Singh and Singh, 2014). Both adults and larvae of *E. oryzae* feed on rice plants, but generally the larval stage causes yield losses as is the case with *L. oryzophilus* (Way, 1990). Everett and Trahan (1967) described the growth habit of *E. oryzae* with the white, legless grubs feeding on roots in the soil from July to September. The attacked plants turn yellow and the overall growth is stunted so that such plants produce only a few tillers. Adults feed on young paddy leaves in flooded or unflooded paddy fields,

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leaving typical feeding scars almost parallel to the venation of leaves. Oviposition also commences when fields are flooded, similar to *L. oryzophilus*. The density of rice root weevil larvae varies greatly across the paddy field, but significant differences have been noticed at different water depths. The nature of damage and biology of *E. oryzae* seems to be similar to that of *L. oryzophilus* in rice fields.

While there is insufficient literature regarding detailed study about *E. oryzae,* for *L. oryzophilus*, several studies have demonstrated that short delays in flooding can reduce yield losses (Rice et al., 1999; Stout et al., 2001) by delaying the commencement of oviposition which occurs only under flooded conditions (Everett and Trahan, 1967; Stout et al., 2002a). The older plants are more tolerant of larval feeding than younger plants (Wu and Wilson, 1997; Stout et al., 2002b). Root damage by larvae results in a reduction in vegetative growth, tillering, grain number and grain weight (Zou et al., 2004). Yield losses caused by root weevil in Louisiana, USA, where *L. oryzophilus* is a particularly severe pest, typically exceed 10%, and can reach 25% or more with severe infestations (Stout et al., 2000). A similar attempt was made under the present investigation to estimate the average yield loss caused by *E. oryzae*. A few chemical management approaches for *E. oryzae* have been studied in the early days in India (Srivastava et al., 1975; Singh et al., 1983); otherwise, pertinent literature is scanty.

The experimental area has received greater attention due to this insect-pest during past years and it was noticed that if the fields were severely infested with rice root weevil, the crop failed to grow and even retransplanting was required. There has not much substantial work carried out in the management of rice root weevil in eastern Uttar Pradesh, India. Therefore, the present study had the following objectives: 1) to study the plant growth parameters in fields infested with rice root weevil; 2) to assess the average yield losses caused by *E. oryzae*; 3) to identify suitable management tactics for rice root weevil by evaluating treatment combinations of different management practices; and 4) to undertake economic analysis of these management options.

Materials and methods

Location

The experiments were conducted by Krishi Vigyan Kendra, Bhadohi (India). The study area was situated on land ranging from 25.12°N to 25.32°N and from 82.12°E to 82.42°E. The typical weather pattern for this region is hot and humid in summer and cold and dry in winter with an intervening rainy season and the temperature is in the range 5–46 °C while the average annual rainfall is 1563 mm (Singh et al., 2008).

Lay out and methodology

Paddy seeds of cultivar MTU-7029 (the most promising cutivar of paddy in the experimental region) were sown to develop the seedlings during the first fortnight of June, 2013 and 2014. Seedling aged 30–35 days old were used for transplanting as per the treatment combinations of seedling and soil treatment. The basal portion of uprooted seedlings was immersed in insecticide solution for 2 h. The experimental plots were arranged in a randomized block design with five replications. The unit plot size was 8 m × 6 m in which the treated seedlings were transplanted at a distance of 10 cm apart in the row with a distance of 20 cm between rows. One week after transplanting the treated seedlings, manual broadcasting of insecticide was done in the standing water.

Selection of test insecticides and treatments applied

The insecticides in the treatment combination were selected on the basis of efficacy against rice water weevil and the existing literature. Chlorpyriphos is the most commonly used insecticide against insect-pests of rice and other crops and it is also effective in controlling soil inhabiting insect-pests (David and Ananthakrishnan, 2004). Cartap hydrochloride is also effective against insect-pests associated with plants by its systemic action (Akayama and Minamida, 1999). The effectiveness of nursery box treatment with cartap hydrochloride against rice water weevil was also assessed (Kayumi et al., 1982). Fipronil is a good larvicide and effective against coleopterous larvae in soil and is also used as a prophylactic seed treatment having also been tested against rice water weevil (Greene, 2003). Table 1 provides the details of the treatment applications.

Data collection

At 2 mth after transplanting, the evaluation of rice root weevil larvae was carried out. Three plant core samples, approximately 10 cm in diameter by 0.1 m depth, were taken from each plot at 2 mth after permanent flooding as the occurrence of *E. oryzae* was noticed from July to September and hence sampling was done at the stated time. Each plant core was washed with water to loosen the soil and the larvae were removed from the roots and counted. The number of tillers/hill and the number of panicles/hill were also observed. Yield data were collected from individual plots.

Statistical analysis

The data collected from the experiments were subjected to analysis of variance for different treatments. Fisher's protected critical difference (CD) test was used to indicate the difference between the treatments at the probability level of $p < 0.05$ following the procedure described by Gomez and Gomez (1984).

Economic analysis

To study the economic parameters, the cost of production was broken down into the cost of seed, nursery raising, field preparation, transplanting, fertilizer application, irrigation, weeding and harvesting. However, the cost of protection consisted of the cost of insecticides and application. Thus, the total cost was obtained by summing the cost of production and cost of protection. The gross return was computed by the sale of produce as per the approved rate by the Government of India. Net return was obtained by subtracting the gross cost from the gross return.

The benefit:cost (B:C) ratio was also determined from the marketable yield and the cost of treatments incurred in the study to evaluate the economic viability of appropriate technology management against *E. oryzae*. The market price of paddy, the rate of insecticide application and labor costs were assumed at the approved government levels to compute the B:C ratio using equation (1):

$$\text{B:C } ratio = \frac{\text{Value of yield over control(\$/t)}}{\text{Total cost of production(\$/ha)}} \qquad (1)$$

Results

As with *L. oryzophilus,* similar results were observed with *E. oryzae* where the attack was more pronounced in younger plants

Table 1
Treatments tested in the study.

Treatment code	Description
T1	Farmers' practice (no use of chemicals for the management of rice root weevil)
T2	Seedling treatment with chlorpyriphos at 3 mL/L of water
T3	Seedling treatment with chlorpyriphos at 3 mL/L of water + Soil application with chlorpyriphos 30 emulsifiable concentrate at 4 L/ha
T4	Seedling treatment with chlorpyriphos at 3 mL/L of water + Soil application with fipronil 0.3 granules at 20 kg/ha
T5	Seedling treatment with chlorpyriphos at 3 mL/L of water + Soil application with cartap hydrochloride 4 granules at 20 kg/ha

and where it was noticed that infestation takes place in young (20–25 days old) seedlings.

Efficacy of insecticides

It is evident from Table 2 that during 2013, the average population of *E. oryzae* weevils was 23.53 per three samples under no weevil management practices. However, the least population of weevils observed was 3.67 in the seedling treatment with chlorpyriphos and soil application with cartap hydrochloride (T5) followed by 4.53 in the seedling treatment with a soil application of fipronil (T4). The average populations did not vary significantly between T5 and T4. It was found in the treatment comprising both the seedling treatment and soil application with chlorpyriphos (T3) that the average population was 5.60 while it was 7.67 in the treatment comprised only seedling treatment (T2). The weevil populations in T3 and T2 did not vary significantly but the population in T2 varied significantly from T4 and T5. Similarly, the weevil population in T1 varied significantly from T2, T3, T4 and T5.

Table 3 presents the data on different crop management parameters observed during 2014. Under no weevil management practices (T1), the population of weevils per three samples was the highest (32.53) while it was the least (3.13) for T5. A lower weevil population was also observed in T4 (5.20), T3 (5.40) and T2 (8.20). While there was a significant difference among the populations observed in T4 (5.20), T3 (5.40) and T2 (8.20), there were statistically different populations observed in T5 and T4. Though the populations in T3 and T2 were not significantly different, they were significantly different from the populations in T1, T4 and T5.

It is also apparent from Fig. 1 that the highest percentage reduction of weevil population was in T5 (84.40% and 90.38% during 2013 and 2014, respectively) in comparison to farmers' practice (T1—no weevil management practices followed). However, reductions of 80.74%, 76.20% and 67.40% were observed in T4, T3 and T2, respectively, during 2013 and similarly, reductions of 84.01%, 83.40% and 74.79% in T4, T3 and T2, respectively, in comparison to T1 during 2014.

Agronomic parameters

The highest number of tillers/hill (25.00) was obtained with T5 followed by T4 (24.80), T3 (23.00), T2 (21.40) and T1 (16.20), respectively, during 2013. The numbers of tillers in T5 and T4 were not statistically different and neither were the numbers of tillers in T3 and T2, but the number of tillers in T5 varied significantly with the numbers of tillers in T3, T2 and T1 (Table 2).

Similarly, the highest number of panicles/hill was 20.00 in T5 followed by 18.20 in T4 and T3, 16.20 in T2 and the least number of panicles/hill was 11.20 in T1. The number of panicles/hill in T5 was significantly greater than in all other treatments (Table 2).

The highest yield (5.41 t/ha) was observed in T5 and the lowest (3.01 t/ha) in T1 where no weevil management practices were followed. The yield was 5.38 t/ha in T4 followed by 5.06 t/ha in T3 and 4.78 t/ha in T2. The yield data in T5 and T4 were not significantly different, as was also the case for T3 and T2, but the yield in T5 was significantly different from T3, T2 and T1 during 2013 (Table 2).

Table 3, for 2014, also shows that the number of tillers/hill was highest in T5 (23.60) followed by T3 (21.40), T4 (20.80), T2 (20.20) and the lowest number of tillers was in T1. The numbers of tillers/hill in T4 and T3 were not significantly different but the number of tillers in T5 was significantly greater than in all other treatments.

Similarly, in 2014, the number of panicles/hill was the highest in T5 (19.40) followed by T3 (16.80), T2 (15.80) and T4 (15.60). The lowest number of panicles/hill was observed in T1 (13.20). It is interesting to note that the numbers of panicles/hill in T4, T3 and T2 were not significantly different but the number of panicles/hill in T5 was significantly different from all other treatments, as was also the case was for the number of tillers/hill (Table 3).

The yield data from 2014 revealed that the highest yield (4.57 t/ha) was observed in T5 followed by T3 (4.32 t/ha) and T4 (4.28 t/ha). The yield was 3.93 t/ha in T2 and 3.38 t/ha in T1. The yields were not significantly different between T4 and T3. However, the yields from T2 and T1 were significantly different and the yield from T5 was significantly greater than the other treatments (Table 3).

Table 2
Crop management parameters observed during 2013.

Treatment code[1]	Average population of weevils/3 samples	Number of tillers/hill	Number of panicles/hill	Yield (t/ha)
T1	23.53^{a}	16.20^{d}	11.20^{d}	3.01^{c}
T2	7.67^{b}	21.40^{c}	16.20^{c}	4.78^{b}
T3	5.60^{bc}	23.00b^{c}	18.20^{b}	5.06^{b}
T4	4.53^{c}	24.80^{ab}	18.20^{b}	5.38^{a}
T5	3.67^{c}	25.00^{a}	20.00^{a}	5.41^{a}
CD[2] (0.05)	2.63	1.98	1.25	0.29
SE (±)	1.24	0.93	0.59	0.14

[1] T1 = farmers' practice (no use of chemicals for the management of rice root weevil); T2 = seedling treatment with chlorpyriphos at 3 mL/L of water; T3 = seedling treatment with chlorpyriphos at 3 mL/L of water + soil application with chlorpyriphos 30 emulsifiable concentrate at 4 L/ha; T4 = seedling treatment with chlorpyriphos at 3 mL/L of water + soil application with fipronil 0.3 granules at 20 kg/ha; T5 = seedling treatment with chlorpyriphos at 3 mL/L of water + soil application with cartap hydrochloride 4 granules at 20 kg/ha.

[2] CD = critical difference.

[3] Different lowercase superscript letters in the same column are significantly different at $p < 0.05$.

Table 3
Crop management parameters observed during 2014.

Treatment code[1]	Average population of weevils/3 samples	Number of tillers/hill	Number of panicles/hill	Yield (t/ha)
T1	32.53^{a}	17.40^{c}	13.20^{c}	3.38^{d}
T2	8.20^{b}	20.20^{b}	15.80^{b}	3.93^{c}
T3	5.40^{b}	21.40^{b}	16.80^{b}	4.32^{b}
T4	5.20^{c}	20.80^{b}	15.60^{b}	4.28^{b}
T5	3.13^{d}	23.60^{a}	19.40^{a}	4.57^{a}
CD[2] (0.05)	1.70	1.23	1.51	0.15
SE (±)	0.80	0.58	0.71	0.07

[1] T1 = farmers' practice (no use of chemicals for the management of rice root weevil); T2 = seedling treatment with chlorpyriphos at 3 mL/L of water; T3 = seedling treatment with chlorpyriphos at 3 mL/L of water + soil application with chlorpyriphos 30 emulsifiable concentrate at 4 L/ha; T4 = seedling treatment with chlorpyriphos at 3 mL/L of water + soil application with fipronil 0.3 granules at 20 kg/ha; T5 = seedling treatment with chlorpyriphos at 3 mL/L of water + soil application with cartap hydrochloride 4 granules at 20 kg/ha.

[2] CD = critical difference.

[3] Different lowercase superscript letters in the same column are significantly different at $p < 0.05$.

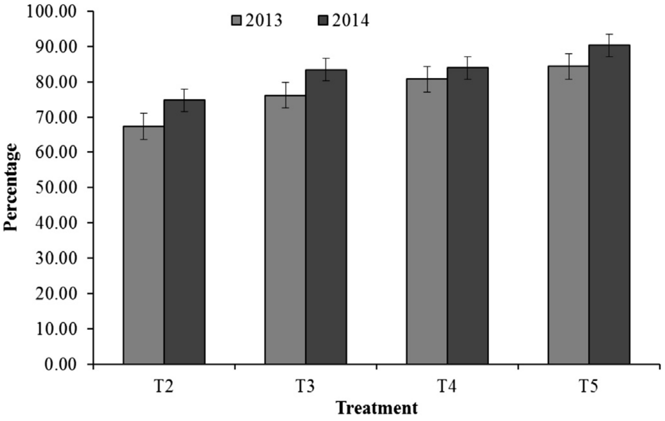

Fig. 1. Percentage reduction of rice root weevil against traditional farmers' practice (error bars indicate ±SE; T1 = farmers' practice (no use of chemicals for the management of rice root weevil); T2 = seedling treatment with chlorpyriphos at 3 mL/L of water; T3 = seedling treatment with chlorpyriphos at 3 mL/L of water + soil application with chlorpyriphos 30 emulsifiable concentrate at 4 L/ha; T4 = seedling treatment with chlorpyriphos at 3 mL/L of water + soil application with fipronil 0.3 granules at 20 kg/ha; T5 = seedling treatment with chlorpyriphos at 3 mL/L of water + soil application with cartap hydrochloride 4 granules at 20 kg/ha).

Economic parameters

The economic parameters of cultivation of paddy during 2013 and 2014 are presented in Table 4. During both years of study, the gross cost of T1, where no weevil management practices were followed, was USD 611.71/ha. The cost incurred in T2 and T3 was USD 634.65/ha and USD 660.87/ha, respectively. However, the gross cost was the same (USD 653.58/ha) in T4 and T5. The highest gross return was observed from T5 (USD 1142.09/ha) followed by T4 (USD 1137.02/ha), T3 (USD 1069.44/ha), T2 (USD 1010.31/ha) and T1 (USD 635.25/ha) during 2013. During 2014, the highest gross return was observed in T5 (USD 965.12/ha), followed by T3 (USD 912.32/ha), T4 (USD 903.87/ha), T2 (USD 829.96/ha) and T1 (USD 713.81/ha). The net return followed a similar pattern for both years. The highest net return was obtained from T5 (USD 488.51/ha in 2013 and USD 311.54/ha in 2014) and the lowest from T1 of only USD 23.54/ha in 2013 and USD 102.10/ha in 2014.

Table 4 shows that T5 had the highest B:C values (1.75 in 2013 and 1.48 in 2014) of all treatments. The second highest B:C values of 1.74 and 1.38 in 2013 and 2014, respectively, were for T4.

Discussion

Due to the increasing importance of *L. oryzophilus* (Lee and Uhm, 1993; Zhai et al., 1997; Saito et al., 2005) and *E. oryzae* in the respective regions, suitable management practices of rice root weevil were studied. *L. oryzophilus*, has established as an important insect pest of rice in the USA and has recently emerged as a major pest of rice in Asia (Heinrichs and Quisenberry, 1999). In the Indian context, the seriousness of *E. oryzae* has also been documented by Tirumala Rao (1952), Srivastava et al. (1975) and Singh et al. (1983). Yield losses of 20% or more have been reported in both Asia and the USA (Shang and Zhai, 1997; Stout et al., 2000). Similarly, *E. oryzae* is becoming widespread in most parts of India and scant literature is available on the rice root weevil. The occurrence of *E. oryzae* was noticed in the early days of transplanting (Singh and Singh, 2014). The yield losses caused by *E. oryzae* similarly varied from 26.03% to 44.36% under the present investigation. A suitable management practice for the rice root weevil will depend on an understanding of the mechanisms by which feeding of this pest reduces the yield. Previous reports have implicated reductions in tillering as a major mechanism of yield loss (Grigarick, 1984; Hesler et al., 2000). The

Table 4
Economic parameters of cultivation of paddy during 2013 and 2014.

Treatment code[a]	Gross cost (USD/ha)		Gross return[b] (USD/ha)		Net return (USD/ha)		Benefit/cost ratio	
	2013	2014	2013	2014	2013	2014	2013	2014
T1	611.71	611.71	635.25	713.81	23.54	102.10	1.04	1.17
T2	634.65	634.65	1010.31	829.96	375.66	195.31	1.59	1.31
T3	660.87	660.87	1069.44	912.32	408.58	251.46	1.62	1.38
T4	653.58	653.58	1137.02	903.87	483.44	250.29	1.74	1.38
T5	653.58	653.58	1142.09	965.12	488.51	311.54	1.75	1.48

[a] T1 = farmers' practice (no use of chemicals for the management of rice root weevil); T2 = seedling treatment with chlorpyriphos at 3 mL/L of water; T3 = seedling treatment with chlorpyriphos at 3 mL/L of water + soil application with chlorpyriphos 30 emulsifiable concentrate at 4 L/ha; T4 = seedling treatment with chlorpyriphos at 3 mL/L of water + soil application with fipronil 0.3 granules at 20 kg/ha; T5 = seedling treatment with chlorpyriphos at 3 mL/L of water + soil application with cartap hydrochloride 4 granules at 20 kg/ha.

[b] Flat rate of sale at USD 18.21/t as grain in both years.

current study also confirmed this effect and, in addition, documented the effects on two other yield components of cultivar MTU-7029—the number of tillers/hill and the number of panicles/hill. Here, the seedling treatment with chlorpyriphos prior to transplanting followed by soil application with different insecticides reduced considerably the damage caused by root weevil in paddy. Srivastava et al. (1975) also observed that top dressing with 10% Birlane granules at 20 kg/ha was the most effective measure for the management of *E. oryzae*.

In the vegetative stage, removal of root biomass led to a reduction in tillering and in total shoot biomass. The reduction in the number of tillers/hill was 35.2% and 26.27% during 2013 and 2014, respectively. Seedling treatment with chlorpyriphos prior to transplanting followed by soil application with different insecticides improved the numbers of tillers and panicles. Studies conducted by N'Guessan et al. (1994) on rice water weevil also documented a reduction in plant height and other parameters of vegetative growth. Panicle density, grain weight and grains per panicle were reduced at the reproductive stage, while panicle density and grain weight were also reduced by 12% and 2%, respectively.

Though the current study revealed that injury inflicted by rice root weevil larvae is a chronic process, the infestation of weevil larvae on roots probably began almost immediately after flooded irrigation. The flooded field conditions are very much conducive to damage when plants are at about the tillering stage (Stout et al., 2013). Therefore, a seedling treatment alone or a soil application of insecticides cannot reduce the crop damage for a longer duration. No significant difference was observed in the number of tillers/hill in the soil applications with cartap hydrochloride and fipronil, but a significant difference was observed in the number of panicles/hill which ultimately influenced the yield. Tillering has also significantly influenced the production of panicles in rice in the case of rice water weevils (Miller et al., 1991; Wu et al., 1998); subsequently panicle density is highly correlated with grain yield (Counce and Wells, 1990; Gravois and Helms, 1992). Reduction in tillering and panicle density was not the only mechanism whereby rice water weevil feeding reduced yields but such feeding also resulted in reductions in shoot biomass, total leaf area and thus total plant photosynthates, which in turn are responsible for grain filling (Yoshida, 1981; Dunand, 1999; Sheehy, 2000). Yield losses also resulted from the 44.0% and 31.96% reductions in the number of panicles/hill during 2013 and 2014, respectively. Thus, decreases in grain numbers may be due to less photosynthesis in weevil-damaged plants. Therefore, all the possible factors responsible for reductions in yield should be discouraged during cultivation practices, to improve the assimilation of photosynthates. The effect on yield components was more pronounced in 2013 than in 2014. This may have been due to tolerance characteristics being greatly influenced by the environment (Strauss and Agrawal, 1999).

In conclusion, feeding by rice root weevil has a great effect on multiple vegetative and reproductive characters in rice. Reductions in the numbers of tillers and panicles are important and yield is affected as well. Therefore, to avoid damage by root weevil from the time of transplanting, it is recommended to apply a treatment of seedlings with chlorpyriphos at 3 mL/L of water followed by a soil application prior to transplanting with cartap hydrochloride at 20 kg/ha. The highest benefit-cost ratio may be achieved by this root weevil management practice in areas where *E. oryzae* is emerging as a threat in the cultivation of paddy.

Conflict of interest

There is no conflict of interest.

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